

Claims

1. A method for drying a workpiece that has been immersed in a first processing liquid, the method comprising the steps of:

withdrawing the workpiece at a selected withdrawal rate from a first liquid;

as the workpiece is withdrawn from the first liquid, transferring to least one exposed surface of the workpiece a second processing liquid, where the second liquid has a surface tension that is less than 17 dynes/cm, and has a second liquid density that is much greater than density of the first liquid;

whereby at least one exposed surface of the workpiece dries in a drying time interval whose length does not exceed a range of 30-45 seconds.

2. The method of claim 1, further comprising the step of choosing said second liquid from the class consisting of hydrofluoroether and an azeotrope of hydrofluoroether, maintained at a selected temperature in the range 20-60 °C.

3. The method of claim 2, further comprising the steps of:

maintaining said second liquid at a selected temperature in the range of 30-60 °C; and

withdrawing said workpiece from said first liquid at a withdrawal rate in the range of 0.5-5 cm/sec.

4. The method of claim 1, further comprising the step of choosing as said first liquid de-ionized water, maintained at a selected temperature in the range of 10-90 °C.

5. The method of claim 1, wherein said step of transferring said drying liquid to said exposed surface of said workpiece comprises spraying said second liquid onto a selected portion of said exposed surface of said workpiece.

6. The method of claim 5, wherein said step of transferring said second liquid to said at least one exposed surface of said workpiece comprises the steps of:

directing a sheet of said second liquid in a selected direction toward said at least one exposed surface of said workpiece so that a selected region, having a selected orientation relative to a vertical direction, of said at least one exposed surface is wetted by the sheet of said second liquid; and

moving at least one of said workpiece and the sheet of said second liquid so that substantially all regions of said at least one exposed surface of said workpiece are wetted by the sheet of said second liquid.

7. The method of claim 6, further comprising the step of choosing said selected orientation of said selected region from a class of orientations consisting of vertical orientation, horizontal orientation and diagonal orientation.

8. The method of claim 6, further comprising the steps of:

directing a second sheet of said second liquid in a selected direction toward said a second exposed surface of said workpiece so that a second selected region, having a second selected orientation relative to a vertical direction, of the second exposed surface is wetted by the second sheet of said second liquid; and

moving at least one of said workpiece and the second sheet of said second liquid so that substantially all regions of the second exposed surface of said workpiece are wetted by the second sheet of said second liquid.

9. The method of claim 8, further comprising the steps of:

choosing said first selected orientation of said selected region from a first class of orientations consisting of vertical orientation, horizontal orientation and diagonal orientation; and

choosing said second selected orientation of said second selected region from a second class of orientations consisting of vertical orientation, horizontal orientation and diagonal orientation.

10. The method of claim 9, further comprising the step of choosing said first selected orientation and said second selected orientation independently of each other.

11. The method of claim 6, further comprising the step of rotating said selected direction of said sheet of said second liquid relative to said workpiece so that substantially all regions of said at least one exposed surface of said workpiece are wetted by said sheet of said second liquid.

12. The method of claim 1, wherein said step of transferring said second liquid to said exposed surface of said workpiece comprises dribbling said second liquid onto a selected region of said exposed surface of said workpiece.

13. A method for cleaning a workpiece, the method comprising the steps of:

transferring to least one exposed surface of the workpiece a processing liquid, where the liquid has a surface tension that is less than 17 dynes/cm and has a liquid density that is much greater than the density of water;

whereby contaminants on at least one exposed surface of the workpiece are removed from the at least one exposed surface.

14. The method of claim 13, further comprising the step of choosing said processing liquid from the class consisting of hydrofluoroether and an azeotrope of hydrofluoroether, maintained at a selected temperature in the range 20-60 °C.

15. The method of claim 13, wherein said step of transferring said liquid to said exposed surface of said workpiece comprises spraying said liquid onto a selected portion of said exposed surface of said workpiece.

16. The method of claim 15, wherein said step of transferring said liquid to said at least one exposed surface of said workpiece comprises the steps of:

directing a sheet of said liquid in a selected direction toward said at least one exposed surface of said workpiece so that a selected region, having a selected orientation relative to a vertical direction, of said at least one exposed surface is wetted by the sheet of said liquid; and

moving at least one of said workpiece and the sheet of said liquid so that substantially all regions of said at least one exposed surface of said workpiece are wetted by the sheet of said liquid.

17. The method of claim 16, further comprising the step of choosing said selected orientation of said selected region from a class of orientations consisting of vertical orientation, horizontal orientation and diagonal orientation.

18. The method of claim 16, further comprising the steps of:

directing a second sheet of said second liquid in a selected direction toward said a second exposed surface of said workpiece so that a second selected region, having a second selected orientation relative to a vertical

direction, of the second exposed surface is wetted by the second sheet of said second liquid; and

moving at least one of said workpiece and the second sheet of said second liquid so that substantially all regions of the second exposed surface of said workpiece are wetted by the second sheet of said second liquid.

19. The method of claim 18, further comprising the steps of:

choosing said first selected orientation of said selected region from a first class of orientations consisting of vertical orientation, horizontal orientation and diagonal orientation; and

choosing said second selected orientation of said second selected region from a second class of orientations consisting of vertical orientation, horizontal orientation and diagonal orientation.

20. The method of claim 19, further comprising the step of choosing said first selected orientation and said second selected orientation independently of each other.

21. The method of claim 16, further comprising the step of rotating said selected direction of said sheet of said liquid relative to said workpiece so that substantially all regions of said at least one exposed surface of said workpiece are wetted by said sheet of said liquid.

22. A method for drying a workpiece, the method comprising the step of:

withdrawing a workpiece from a first processing liquid, having a first liquid density, at a selected withdrawal rate and forming transitory first and second zones and a third zone on a surface of the workpiece, where the first zone is immersed in and covered with the first liquid, the second zone is not immersed in the first liquid and is at least partly covered with a second

processing liquid, the third zone is not immersed in the first liquid and is substantially free of the first liquid and of the second liquid, the second zone is located between the first zone and the third zone, and the second liquid is less polar than the first liquid, has a surface tension that is less than 17 dynes/cm, and has a second liquid density that is much greater than the first liquid density;

whereby an exposed surface of the workpiece in the third zone dries in a drying time interval whose length does not exceed 30 seconds.

23. The method of claim 22, further comprising the step of choosing said second liquid from the class consisting of hydrofluoroether and an azeotrope of hydrofluoroether, maintained at a selected temperature in the range 20-60 °C.

24. The method of claim 22, further comprising the step of choosing as said first liquid de-ionized water, maintained at a selected temperature in the range of 20-60 °C.

25. The method of claim 24, further comprising the steps of:
maintaining said second liquid at a selected temperature in the range of 30-60 °C; and

withdrawing said workpiece from said first liquid at a withdrawal rate in the range of 0.5-5 cm/sec.

26. The method of claim 22, further comprising the step of withdrawing said workpiece from said first liquid and forming a transitory fourth zone on said surface of said workpiece, located between said first zone and said second zone, that is not immersed in said first liquid but has a residue of said first liquid present in the fourth zone.

27. A method for drying a workpiece, the method comprising the steps of:

positioning the workpiece in a selected orientation relative to a vertical orientation;

transferring to a selected portion of at least one exposed surface of the workpiece a selected processing liquid, where the liquid has a surface tension that is less than 17 dynes/cm and has a liquid density that is much greater than the density of water; and

moving the selected portion of the at least one exposed surface of the workpiece so that substantially all regions of the at least one exposed surface are wetted by the liquid,

whereby the at least one exposed surface of the workpiece dries in a drying time interval whose length does not exceed 45 seconds.

28. The method of claim 27, further comprising the step of selecting said portion of said at least one exposed surface of said workpiece to be an approximately horizontally oriented strip of selected strip width that extends across said at least one exposed surface of said workpiece.

29. The method of claim 27, further comprising the step of selecting said portion of said at least one exposed surface of said workpiece to be an approximately vertically oriented strip of selected strip width that extends across said at least one exposed surface of said workpiece.

30. The method of claim 27, further comprising the step of selecting said portion of said at least one exposed surface of said workpiece to be a strip of selected strip width that extends across said at least one exposed surface of said workpiece in a diagonal direction.

31. A method for cleaning a workpiece, the method comprising the steps of:

positioning the workpiece in a selected orientation relative to a vertical orientation;

transferring to a selected portion of at least one exposed surface of the workpiece a selected processing liquid, where the liquid has a surface tension that is less than 17 dynes/cm and has a liquid density that is much greater than the density of water; and

moving the selected portion of the at least one exposed surface of the workpiece so that substantially all regions of the at least one exposed surface are wetted by the liquid,

whereby contaminants on at least one exposed surface of the workpiece are removed from the at least one exposed surface.

32. The method of claim 31, further comprising the step of selecting said portion of said at least one exposed surface of said workpiece to be an approximately horizontally oriented strip of selected strip width that extends across said at least one exposed surface of said workpiece.

33. The method of claim 31, further comprising the step of selecting said portion of said at least one exposed surface of said workpiece to be an approximately vertically oriented strip of selected strip width that extends across said at least one exposed surface of said workpiece.

34. The method of claim 31, further comprising the step of selecting said portion of said at least one exposed surface of said workpiece to be a strip of selected strip width that extends across said at least one exposed surface of said workpiece in a diagonal direction.

35. A method for drying a workpiece, the method comprising the steps of:

immersing the workpiece in a selected processing liquid, where the liquid has a surface tension that is less than 17 dynes/cm, and has a liquid density that is much greater than the density of water;

forming a selected flow pattern of the liquid that is approximately circular across at least a portion of at least one exposed surface of the workpiece, for a selected time interval; and

removing the workpiece from the liquid,

whereby the at least a portion of the at least one exposed surface of the workpiece dries within 45 seconds after being removed from the liquid.

36. The method of claim 35, further comprising the step of choosing said liquid from the class consisting of hydrofluoroether and an azeotrope of hydrofluoroether, maintained at a selected temperature in the range 20-60 °C.

37. The method of claim 35, further comprising the step of choosing said flow pattern to have an approximate center for said approximately circular flow that is spaced apart from said workpiece.

38. The method of claim 35, further comprising the step of choosing said flow pattern to have an approximate center for said approximately circular flow that is located within said at least one portion of said at least one exposed surface of said workpiece.

39. The method of claim 35, further comprising the step of forming said approximately circular flow pattern with an associated liquid angular velocity in the range 0.2-500 radians per second.

40. The method of claim 39, further comprising the step of forming a second selected flow pattern of said liquid that is approximately circular across at least a second portion of said at least one exposed surface of said workpiece, for a second selected time interval, where said first portion and the second portion of said at least one exposed surface of said workpiece overlap each other.

41. A method for cleaning a workpiece, the method comprising the steps of:

immersing the workpiece in a selected processing liquid, where the liquid has a surface tension that is less than 17 dynes/cm, and has a liquid density that is much greater than the density of water;

forming a selected flow pattern of the liquid that is approximately circular across at least a portion of at least one exposed surface of the workpiece, for a selected time interval; and

removing the workpiece from the liquid,
whereby contaminants are removed from the at least one exposed surface.

42. The method of claim 41, further comprising the step of choosing said liquid from the class consisting of hydrofluoroether and an azeotrope of hydrofluoroether, maintained at a selected temperature in the range 20-60 °C.

43. The method of claim 41, further comprising the step of choosing said flow pattern to have an approximate center for said approximately circular flow that is spaced apart from said workpiece.

44. The method of claim 41, further comprising the step of choosing said flow pattern to have an approximate center for said approximately circular flow that is located within said at least one portion of said at least one exposed surface of said workpiece.

45. The method of claim 44, further comprising the step of forming said approximately circular flow pattern with an associated liquid angular velocity in the range 0.2-500 radians per second.

46. The method of claim 41, further comprising the step of forming a second selected flow pattern of said liquid that is approximately circular across at least a second portion of said at least one exposed surface of said workpiece, for a second selected time interval, where said first portion and the second portion of said at least one exposed surface of said workpiece overlap each other.

47. A method for drying a workpiece, the method comprising the steps of:

immersing the workpiece in a selected processing liquid that has a surface tension that is less than 17 dynes/cm and that has a liquid density that is much greater than the density of water, where the liquid is heated to a selected temperature that is less than the boiling temperature of the liquid, for a selected immersion time interval of at least 5 seconds;

subjecting the workpiece to ultrasonic vibrations in a selected frequency range within the liquid for at least a portion of the immersion time interval; and

withdrawing the workpiece from the liquid at a selected withdrawal rate,

whereby an exposed surface of the workpiece dries after the workpiece surface is withdrawn from the liquid in a drying time interval whose length does not exceed 30 seconds.

48. The method of claim 47, further comprising the step of choosing said liquid from the class consisting of hydrofluoroether and an azeotrope of hydrofluoroether, maintained at a selected temperature in the range 20-60 °C.

49. The method of claim 47, further comprising the steps of:
maintaining said liquid at a selected temperature in the range of 30-60 °C; and

withdrawing said workpiece from said liquid at a withdrawal rate in the range of 0.5-5 cm/sec.

50. A method for cleaning a workpiece, the method comprising the steps of:

immersing the workpiece in a selected processing liquid that has a surface tension that is less than 17 dynes/cm and that has a liquid density that is much greater than the density of water, where the liquid is heated to a selected temperature that is less than the boiling temperature of the liquid, for a selected immersion time interval of at least 5 seconds;

subjecting the workpiece to ultrasonic vibrations in a selected frequency range within the liquid for at least a portion of the immersion time interval; and

withdrawing the workpiece from the liquid at a selected withdrawal rate,

whereby contaminants on at least one exposed surface of the workpiece are removed.

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51. The method of claim 50, further comprising the step of choosing said liquid from the class consisting of hydrofluoroether and an azeotrope of hydrofluoroether, maintained at a selected temperature in the range 20-60 °C.

52. The method of claim 51, further comprising the steps of:
maintaining said liquid at a selected temperature in the range of 30-60 °C; and
withdrawing said workpiece from said first liquid at a withdrawal rate in the range of 0.5-5 cm/sec.

52. The method of claim 51, further comprising the steps of:
maintaining said liquid at a selected temperature in the range of 30-60 °C; and
withdrawing said workpiece from said first liquid at a withdrawal rate in the range of 0.5-5 cm/sec.